ESTCP
Cost and Performance Report

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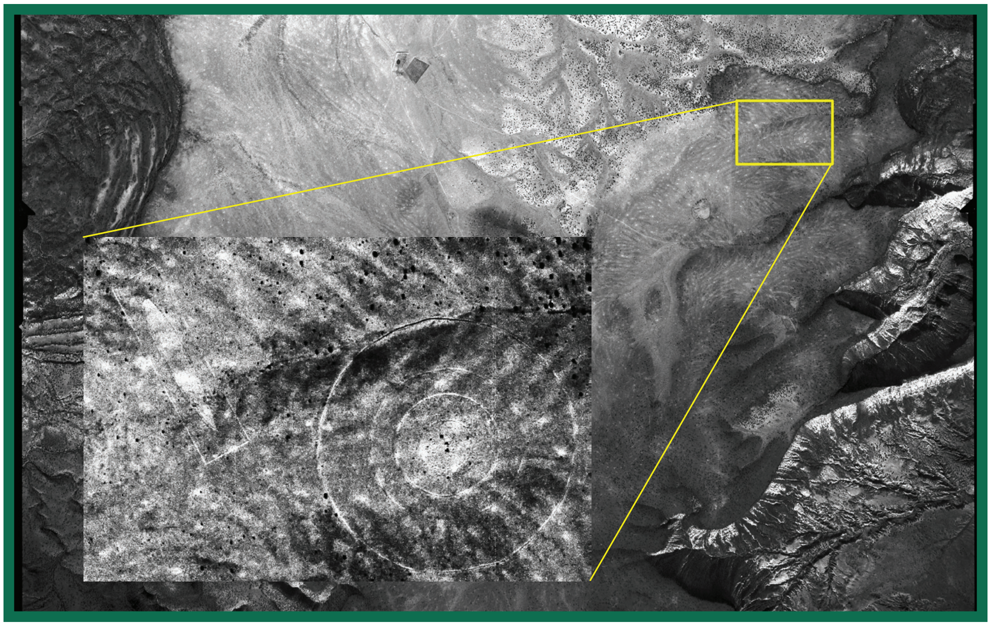

Improved Processing, Analysis and Use of Historical Photography

October 2010

ESTCP

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AOI	area of interest
APFO	Aerial Photography Field Office
ASR	Archive Search Report
ATAGR	Air-To-Air Gunnery Range
DBR	demolition bombing range
DEM	digital elevation model
DERP	Defense Environmental Restoration Program
DIP	digital image processing
DoD	Department of Defense
ESRI	Environmental Systems Research Institute
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Site
GIS	geographic information system
HE	high explosive
MMRP	Military Munitions Response Program
NARA	National Archives and Records Administration
QC	quality control
PA	preliminary assessment
PBR	Precision Bombing Range
PI	photo interpretation
RAC	Risk Assessment Code
SI	site investigation
SORT	Simulated Oil Refinery Target
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS-EDC	U.S. Geological Survey EROS Data Center
WAA	Wide-Area Assessment
WWII	World War II

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1.0 EXECUTIVE SUMMARY

Historical aerial photography is routinely used in support of environmental cleanup operations at many Department of Defense (DoD) sites. The broader use of current best practices for image interpretation and the application of digital image processing (DIP) techniques can improve the amount of information extracted from the photos. This appears especially important at large Formerly Used Defense Sites (FUDS) that were used as practice and demolition bombing ranges (DBR) for bombardier training crews during World War II (WWII). The accurate mapping of range features and the identification of sites where demolition ordnance was used is critical to the cost-effective environmental cleanup and transfer of these properties to other public and private uses.

The goal of this project was to demonstrate techniques to make more effective use of historical photography for environmental cleanup support. Eight study sites located in the Southwestern portion of the United States were selected for the demonstration project. Six of the sites were located in New Mexico and two sites were located in Texas. The sites provided a wide range of sizes, spanning from 1 to 774 square miles.

A comparative analysis of three interpretation methods was undertaken. The baseline method used existing results from photo interpretations (PI) used to develop Archive Search Reports (ASR) for Military Munitions Response Program (MMRP) sites. These interpretations were based on photographic prints and pocket stereoscopes. The second method was based on film diapositives (positive transparencies) and zoom stereoscopes. The third method was based on scanned film that was digitally processed and viewed. Both alternative methods improved upon the baseline method, with the digital processing approach systematically providing the best results. It was observed by the image analysts that routine image enhancement techniques may provide results similar to the more advanced image restoration techniques tested.

Some observations and lessons learned from the demonstration were largely tangent to the primary objectives of the project. One observation was that the all roads should be mapped and considered for their potential use as historical convoy targets. These targets appear to have been transient with no distinguishing appearances. The presence of service roads to nearly all targets was noted. The historical documents mentioned the need to develop roads for periodic maintenance of the targets.

It was recognized during the study that aerial photography archives are dynamic. Collections continue to expand and they are becoming more organized and accessible with improved finding aids. ASR photo search results should be used as a starting point for subsequent site investigations (SI) and remedial efforts, but the photo searches sometimes need to be updated. A substantial amount of additional aerial photography was identified for the sites used for this demonstration project. It allowed the identification of several ranges that had been missed or incorrectly located in previous studies. Although many range features remain apparent on recent photography, some features were no longer evident in as little as four years after range operations were discontinued. Acquiring historical photography during or shortly after range operational periods can be critical to the accurate detection and mapping of range features.

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2.0 INTRODUCTION

Historical aerial photography is routinely used in support of environmental cleanup operations at DoD sites. For large WWII sites with a history of military munitions use, such as practice and DBRs, historical aerial photography can provide a unique source of information. The accurate mapping of range target features is critical to the cost-effective environmental cleanup and transfer of these properties to other public and private uses. The broader use of current best practices for image interpretation and the application of image processing techniques can improve the amount of information extracted from the photos. The goal of this project was to demonstrate how DoD and other organizations can make more effective use of historical aerial photography for environmental cleanup support.

2.1 BACKGROUND

TerraSpectra Geomatics recently provided support to the Albuquerque District of the U.S. Army Corps of Engineers (USACE) to develop a statewide Geographic Information System (GIS) database for New Mexico FUDS. The project had a special emphasis on MMRP sites. As property and range boundaries were initially developed from existing USACE ASR documents, potential limitations of the ASR historical photo reviews were noted. Color digital orthophotos (2005) were used to verify the locations of MMRP site features. Significant offsets between the ASR range locations and their orthophoto locations became evident during quality control (QC) checks of the data. Although ranges are broadly defined by large buffers around targets, detailed SIs that rely on the original ASR locations could provide erroneous results.

Possible causes for the locational offsets and missed features include:

- Orthophotos were not widely available when much of the ASR work was conducted.
- Photographic prints were used rather than positive transparencies (diapositives).
- PIs were performed using pocket stereoscopes.
- Photo dates and/or scales used were not sufficient for identifying range features.

Organizations routinely conducting historical photo analyses for environmental forensics[1] usually make use of diapositives (film positive transparencies) whenever they are available. Diapositives have superior resolution and dynamic range compared to prints and are, therefore, preferred for direct viewing or scanning. The quality of viewing and scanning equipment can also affect interpretation results, as can the expertise level of the photo interpreters.

Since the 1930s, there have been several national programs to collect aerial photography throughout the United States. This photography has special utility for large area studies. The demonstration of techniques for Wide-Area Assessment (WAA) was a recent focus area of the DoD Environmental Security Technology Certification Program (ESTCP) (ESTCP, 2006). A goal of this program was to demonstrate cost-effective methods to allocate cleanup resources.

[1] Such as the U.S. Environmental Protection Agency's (USEPA) Environmental Photo Interpretation Center.

These efforts were based on a multistage or layered approach (high airborne, helicopter, and ground) using a suite of sensors. These sensor systems included orthophotography, light detection and ranging, synthetic aperture radar, hyperspectral imaging, magnetometer arrays, and electromagnetic induction arrays. One limitation noted in studies using optical-based techniques was that the passage of time may result in surface features becoming obscure. The more extensive use of historical photography can provide a baseline WAA methodology that can help minimize this limitation. This demonstration project addresses several aspects of how DoD and other organizations could make better use of historical photography.

2.2 OBJECTIVE OF THE DEMONSTRATION

The primary objective of this project was to compare and evaluate results from three methods for the extraction of information from historical photography. The three methods compared were:

1. Existing ASR mapping procedures—used as a baseline
2. Best standard practices—based on different film media and interpretation equipment
3. Advanced DIP—with image restoration and enhancements.

There was a specific focus on the visual identification and mapping of WWII-era practice and DBRs and their related target features. The improved techniques should also prove useful for other types of environmental cleanup applications where the identification and mapping of historical features could better focus efforts.

Eight project study sites were selected. Sites ranged from a 1-square mile site with a single target to a site of about 774 square miles with 10 ranges. This provided a reasonable sample size in terms of the number of ranges (29) and target features (79). The sites were not randomly selected. They included four properties with several well-defined ranges and four properties for which range locations had not been established in the New Mexico FUDS database.[2]

A secondary objective of this project was to evaluate potential improvements in the detection and mapping of high explosive (HE) bomb craters. If successful, this would have provided an improved means to distinguish between practice and DBR locations. This was approached using both visual interpretation and terrain modeling methods. The high resolution terrain modeling approach was recognized as an exploratory study element. The results for both approaches, discussed in more detail later, did not demonstrate any improved performance over existing procedures.

A final objective of the demonstration was to provide for technology transfer. The development of general guidelines for the processing and interpretation of historical photography, with an emphasis on FUDS applications, supports this objective. This report and subsequent technical presentations and publications will be used to more broadly disseminate the results.

[2] During the course of this project, additional Preliminary Assessment (PA) studies provided accurate locations for two of the four unmapped ranges

2.3 REGULATORY DRIVERS

The environmental cleanup of former DoD ranges is generally conducted under authority of the Comprehensive Environmental Response, Compensation, and Liability Act. Detailed ground investigations and cleanup would be prohibitively expensive unless well-focused to those areas most likely to contain unexploded ordnance or munitions contaminants. The use of historical photography can provide a unique temporal element for large area assessments and facilitate the prioritization of other survey technologies. The use of aerial photography is widely understood and well accepted by the regulatory community (ITRC, 2003).

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3.0 TECHNOLOGY

Key technologies involved in this project included the application of PI, DIP, photogrammetry, and GIS database development. Image restoration, specifically blur removal, was systematically applied prior to standard image enhancements (e.g., brightness and contrast adjustments and image sharpening) as images were preprocessed for digital stereo viewing and orthophoto generation.

3.1 TECHNOLOGY DESCRIPTION

Much of the original ASR mapping was done by visually matching historical photographic features to topographic maps. This method is dependent upon distinct landscape features and can sometimes prove difficult and lead to large positional errors. A wealth of historical documentation and initial site reviews were developed in support of the ASR program, but the results must be carefully reviewed before proceeding with more expensive site-specific field activities. It is important to recognize the potential limitations of the earlier ASR work as follow-on activities are undertaken.

3.1.1 Image Restoration and Enhancement

Until the 1960s for military systems, and much later for most commercial systems, aerial cameras lacked forward-motion compensation. This is a precise mechanical adjustment that is made to account for aircraft movement during film exposure (McDonnell Douglas, 1983). Lens quality has also been improved in newer camera systems. Lens quality and motion blur are key elements affecting image resolution and overall image quality (ASPRS, 1980). Modern digital photogrammetry systems rely on the high quality optics and automated forward-motion compensation available with newer cameras. Image restoration procedures are generally not needed nor available in these digital or “softcopy” systems. The application of image restoration techniques, however, can potentially improve the quality of historical aerial photos and provide the basis for improved interpretations. Image restoration is a well-studied field that is distinctly different from image enhancement. In certain circumstances where lens blur or motion can be well-characterized, image restoration can reveal information that cannot be obtained using routine image enhancement techniques (SWGIT, 2002; Ben-Ezra, 2004; and Simoncelli, 2005). The motion blur example shown in Figure 1 demonstrates this.

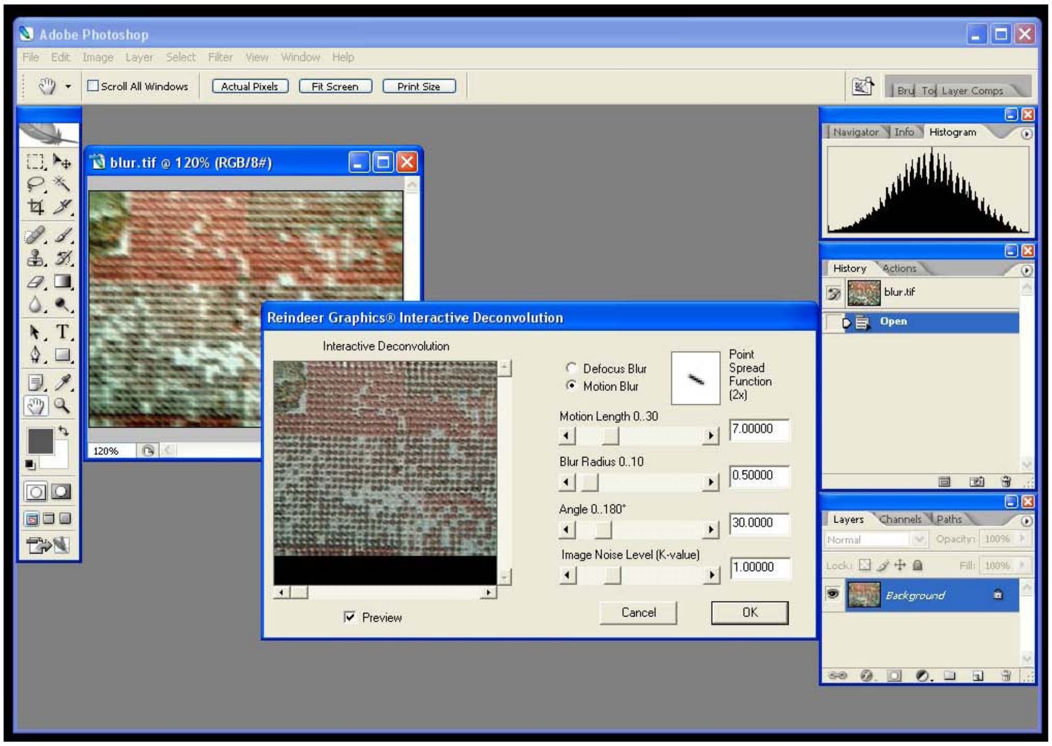

Figure 1. Example of image restoration for motion blur correction.

Original image (left) and motion blur corrected image (center) of aerial imagery of an orchard. Image enhancement techniques cannot recover the imagery detail apparent in the restored image. The amount of motion blur in this image is severe and not typical of historical aerial photography.

Image enhancement techniques are now widely available for digital imagery. Common functions are brightness and contrast adjustments, and edge enhancement or sharpening. It was noted during the course of this project that near real-time adjustments were often important to optimize the resulting image quality. Localized adjustments were often required to enhance specific features of interest. ERDAS® Imagine and Adobe® Photoshop were used for most of the image processing. Figure 2 provides an example of image enhancements applied to historical photography of a practice bombing range located in New Mexico.

3.1.2 Photogrammetry Using Historical Photos

Another area addressed during this project was the lack of camera calibration reports for some sets of older historical aerial photography. Digital photogrammetry systems rely on calibration reports to correct for some lens distortions. The lack of this information requires the use of non-standard procedures for generating digital orthophotos. While simple registration techniques are widely applied, a very limited number of examples of historical orthophotos have been reported in the literature (Slonecker, 2009). For this project, the ERDAS Leica® and Mira Solutions® photogrammetry suites were used for the photogrammetric processing. The ERDAS suite now includes generic camera models and procedures for use when calibration reports are not available.

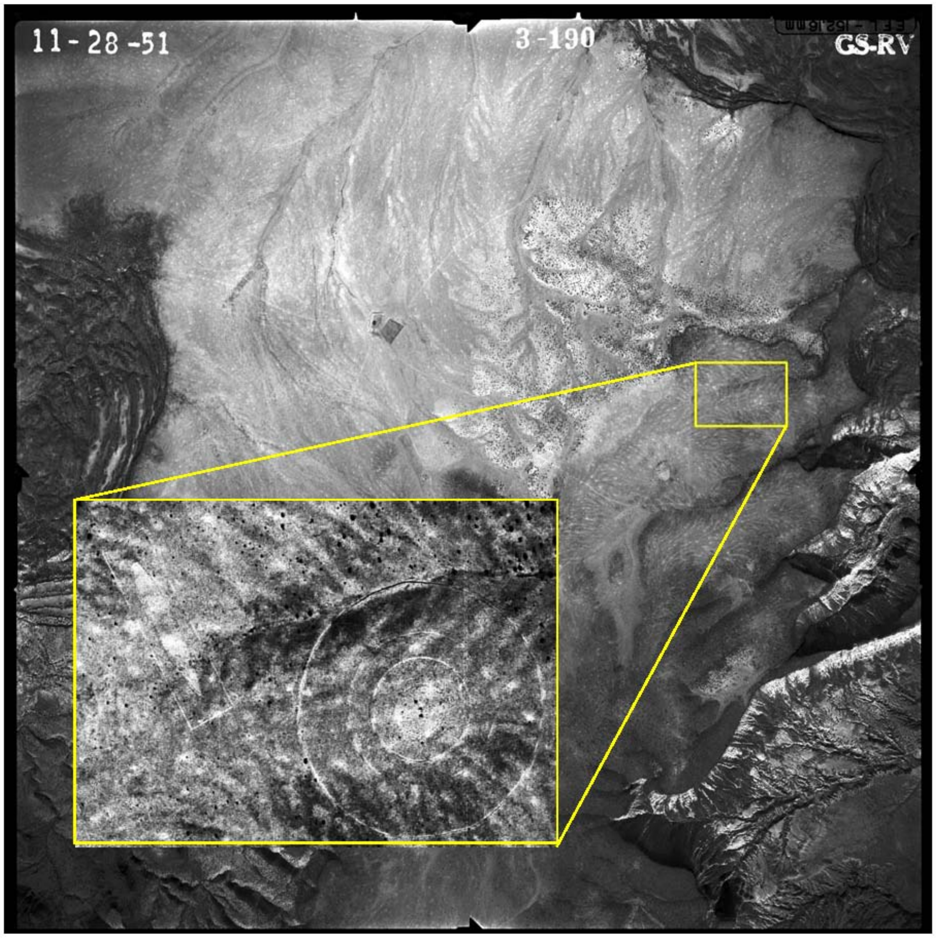

Figure 2. Example of digital enhancement and enlargement of 1951 scanned photograph. The original scale of the 9x9-inch photograph was 1:28,400. It is shown here at approximately 1:40,000 scale (70% of the original). The yellow box area is the location of the practice bombing range that is shown enlarged in the inset. The enlargement and enhancement of the range area shows a distinctive rectangle outline encompassing a ship target. The outer target circle diameter measures 1000 ft and the rectangle measures 800 ft in length. The photo interpretation of prints for the USACE 2005 Preliminary Assessment of this New Mexico site (K06NM0449) identified the circular target but missed the ship target.

3.1.3 Geographic Information Systems

The use of a GIS framework for organizing site imagery and other data can significantly improve interpretation and analysis results. Geospatially organized collateral data and information can often assist interpretation and analyses. The Environmental Systems Research Institute (ESRI)® ArcGIS® software was used to provide this functionality and organize interpretation results.

3.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

A primary advantage of historical photography is that it can provide the appropriate temporal element for past activities of interest. Aerial photographs are unique in providing a visual record or “snapshot in time” of historical site conditions. When suitable photography is available it can prove extremely cost-effective, since no mission deployment costs are involved. Only archive

data searches and reproduction or digital scanning costs are involved to acquire imagery. See an example in Figure 3.

A primary limitation of aerial photography and other optical-based techniques is that they are not directly sensing the presence of munitions but must make use of a surrogate or indicator. Aerial photography requires a surface expression, such as visually distinct range target features or bomb craters, as an indicator for the likely presence of munitions-related materials. The use of historical photography is also limited by the type and quality of photography available. Obviously there are no retroactive options to change the original acquisition parameters.

It was noted during this study that photographic archives are continuing to expand as historical photos are identified and added to the collections. With new finding aids, especially those based on geographic coordinate based databases, they are also becoming easier to search. One result of this is that prior search results cannot be relied upon as complete; new searches often identify additional sets of historical photos. Prior ASR photo searches generally made use of the primary government archives of historical photos: the National Archives and Records Administration (NARA), the U.S. Geological Survey EROS Data Center (USGS-EDC), and the U.S. Department of Agriculture Aerial Photography Field Office (APFO). Additional photography is often available from other federal organizations and especially state and local resources. The region specific resources are more numerous and sometimes more difficult to readily identify. Primary regional sources include private aerial photo firms, university libraries, and state and local governmental organizations. Transportation departments are often a good source at the state and local level. The validation effort for this project made effective use of state and local resources to obtain selected copies from their photographic archive holdings.

The shelf-life of film is limited and a concern for all archives. Shelf-life can vary significantly, from a few years to many decades, depending on storage conditions such as temperature and humidity. Early film was nitrate-based, which had the drawback of decomposing and being extremely flammable. Acetate-based "safety film" was subsequently developed, but cellulose triacetate degradation was reported within a decade of its introduction in 1948. As it became better understood, this problem has become known as the "vinegar syndrome." Once started, rapid deterioration can render the acetate film element past the point of transferability to another medium. Professional archives have standard procedures to monitor and handle this problem.

Conversion to digital format is one option for long-term aerial photo storage. The USGS-EDC no longer provides film copies of their extensive holdings of over 8 million frames of aerial photography. Only digital scans of their film are now available as a standard product. Moving towards digital imagery is therefore now a requirement in order to use some historical archives, and this conversion trend is expected to continue.

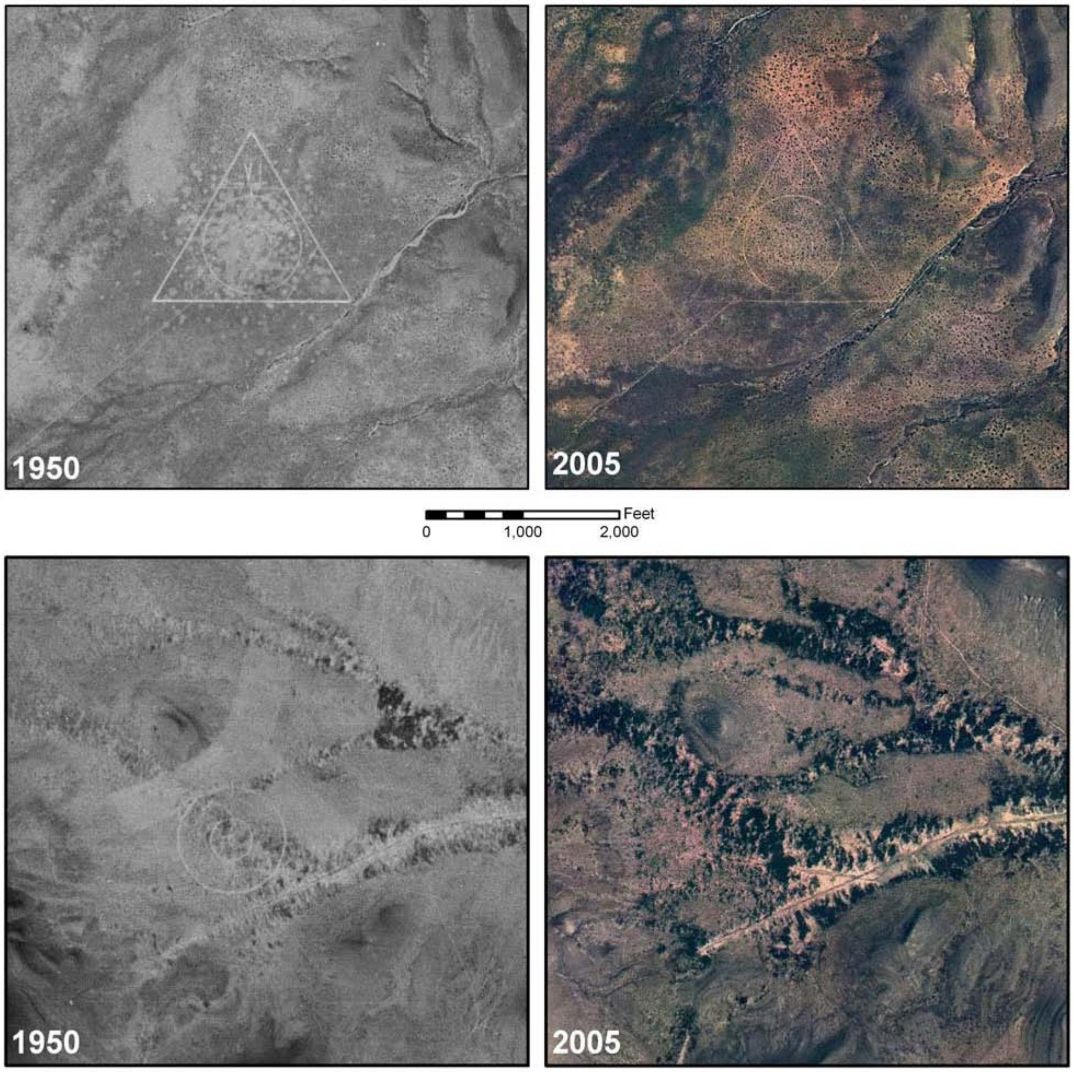

Figure 3. Temporal pairs of targets.

These matched pairs of photographs illustrate former bombing ranges located on the Guadalupe Bombing and Gunnery Range (K06NM033), located in New Mexico. The top pair illustrates a demolition range (designated D-6) that remains distinct on the 2005 imagery, although the craters evident in 1950 (frame 55) are no longer apparent. The bottom pair is a practice bombing range (PB-1) that is composed of a circular target adjacent to a large "Y" shaped air-to-air navigation feature (1950 frame 53). This range is no longer distinct on the 2005 imagery. The 1950 photography was acquired at an original scale of 1:44,000. The 2005 orthophotos were generated at a pixel resolution of 1 m for a statewide orthophoto mapping program. The images above are presented at a nominal scale of 1:20,000.

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4.0 PERFORMANCE OBJECTIVES

Performance objectives for this demonstration project are summarized in Table 1.

Table 1. Performance objectives.

Performance Objective	Metric	Data Required	Success Criteria
Quantitative Performance Objectives			
1. Visual identification of all bombing range areas	Percent detected	Location of ranges	100% detection
2. Limited false alarms for bombing range areas	Percent of areas incorrectly identified as ranges	Location of ranges	< 50% false identifications
3. Identify all range target features (outlines of ships, docks, airstrips, etc.)	Percent detected	Location of range targets	> 90%
4. Limited false alarm rate for range target features (above)	Percent of features incorrectly identified as range target features	Location of range targets	< 50% false identifications
5. Identification of ranges with craters (inferred use of HE munitions)	Percent detected	Location of craters within or near ranges	> 75% detection
6. Feature mapping location accuracy	Average range and target feature mapping location error	Feature centroid location mapped from historical photos onto their corresponding orthophoto locations	< 10 m distance offset
7. Interpretation production rate	Time required to analyze each stereo-pair of photos	Log of analysis time accurate to 10 minutes	Analysis time: < 1 hour per photo pair
8. Orthophotos from historical photos	Average tie and check point location offset errors	Location accuracy of distinct features compared to USGS (or similar) orthophoto	< 10 m distance offset for tie points < 15 m offset for distinct check point features
9. DEM from historical photos	Percent correct detection of craters	Demolition bomb crater feature locations	Improved crater detection performance using restored imagery versus non-restored imagery
Qualitative Performance Objectives			
10. Ease of use and technology transfer	(Not applicable)	Feedback from analysts on the usability of the different procedures and products developed	Completion of general guidelines or protocols for use of historical photos and professional publication(s) of results

DEM = digital elevation model

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5.0 SITE DESCRIPTIONS

The emphasis of this technology demonstration project was on large practice and DBRs. These ranges were originally developed and operational during WWII and shortly thereafter supported bombardier crew training. The target features constructed on these ranges were generally large and distinct, as the training missions were based on visual target identifications.

5.1 SITE SELECTIONS

Eight FUDS MMRP sites were selected for the demonstration. Six of the sites were located in New Mexico, and two were in Texas. Figure 4 presents a map of the study site locations. These sites were believed to be generally representative of environmental and bombing range conditions and target features present in the Southwest region of the United States. Several criteria were used in the selection of the test sites, including range size, availability of WAA data for validation, and sites where target features had not been previously photo verified or unexpected HE debris had been encountered during field investigations (see Table 2). More detailed site histories, characteristics and selection rationale for the eight FUDS MMRP sites that were used for this study are provided in the project final report (TerraSpectra, 2010).

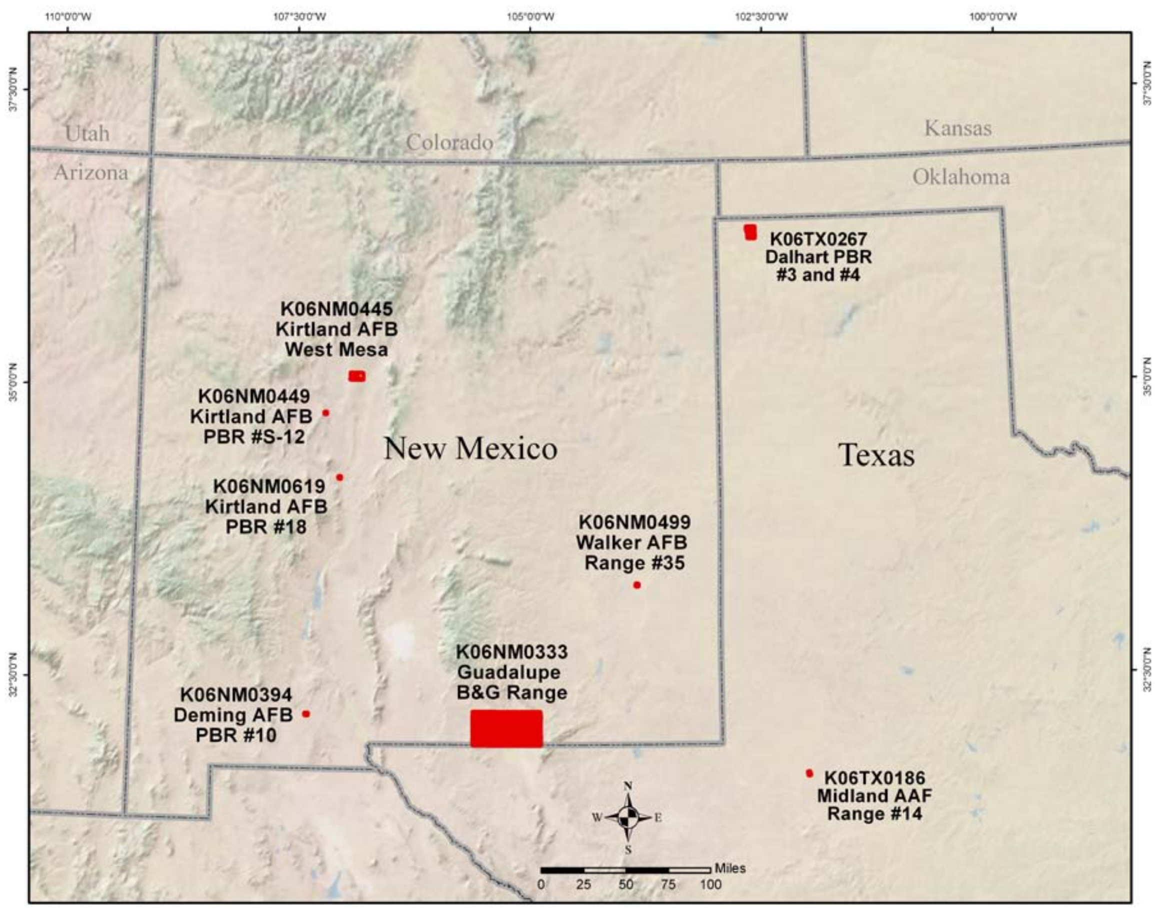

Figure 4. New Mexico and Texas study site locations.

Table 2. Project study sites.

Project # - FUDS ID Study Date	RAC(1) Score	Site Name	Active Period	Range Acres	Property Acres	Comments
NEW MEXICO SITES						
#1 - K06NM0333 ASR 2001	4	Guadalupe Bombing and Gunnery Range	1943-1956	12,539	495,053	Combination of several practice and demolition ranges, with several unmapped navigation markers
#2 - K06NM0394 ASR 1997	4	Deming Air Force Base (AFB) Precision Bombing Range (PBR) #10	1943-1947	649	960	Practice bombing range; no features evident in photos used for original ASR; range considered "missing" (2)
#3 - K06NM0445 ASR 1994	2	Kirtland AFB Ranges – West Mesa	1941-1945	1298	15,246	Combination of multiple practice and one demolition range; WAA study site
#4 - K06NM0449 PA 2005	4	Kirtland AFB PBR #S-12	1942-1946	649	640	Considered "missing" practice range at project start; range found off-site of original property that was field inspected
#5 - K06NM0499 ASR 1998	4	Walker AFB DBR #35	1944-1945	649	1000	Considered "missing" demolition range; range target features were not evident in the ASR photo set
#6 - K06NM0619 PA 2004	4	Kirtland AFB PBR #18 Target S-5	1943-1946	649	640	Considered "missing" practice range at project start; range found off-site of original property that was field inspected
TEXAS SITES						
#7 - K06TX0186 ASR 2000	3	Midland AAF Target Range #14	1942-1947	1646	1646	Unexpected HE debris found during SI; several practice range target features and crater area
#8 - K06TX0267 SI 2009	4	Dalhart PBRs #3 and #4	1943-1945	16,581 (3)	16,581	Combination of two practice and one demolition range, with several target features present; unmapped HE range

(1) RAC: Risk Assessment Code assigned by USACE for each site during initial assessments (1=highest risk, 5=lowest risk).

(2) When this ESTCP project was proposed, four New Mexico FUDS-MMRP sites were not mapped via PI in the available FUDS related documents; all four were included as project sites with a secondary project goal of locating the "missing" ranges; PA documents for two of the sites (K06NM0449 and K06NM0619) were subsequently made available that correctly locate the range locations (but miss the battleship target on K06NM0449). These more recent range maps were used for the comparative analyses.

(3) The original 1998 ASR did not examine aerial photos, so individual ranges were not mapped and the entire property area was considered a range; results from the 2009 SI were used for the comparative analyses.

6.0 TEST DESIGN

Existing range maps developed in support of prior ASRs (or the selected PA and SI studies noted in Table 2) were used as the baseline source of range feature information. These maps are available online from the MMRP SI section of the 2008 Defense Environmental Restoration Program (DERP) Annual Report to Congress (DERP, 2008). It was anticipated that some "new" locations for unmapped bombing range features might be identified. Most of these features were expected to be self-evident upon visual inspection. Only a few questionable features were expected to require field validation.

6.1 CONCEPTUAL EXPERIMENTAL DESIGN

The basic experimental design for this demonstration was to compare interpretation results from existing range maps (ASR or subsequent studies) to those obtained using "best practice" PI procedures and digital image analysis procedures. The new PIs made use of standard procedures developed by the USEPA and other organizations routinely involved in environmental forensics. An experienced analyst interpreted film diapositives using stereo zoom viewing equipment. A separate review of the results by another senior analyst was used to provide a QC check. All differences in interpretations were resolved by a visual review with discussion and consensus. The potential influence of differences among different professional interpreters and the amount of time available to conduct the analyses was recognized but was not addressed as part of this study. All interpreters had at least 10 years professional experience.

The digital processing alternative involved similar interpretation procedures, but was based on digitally pre-processed imagery rather than film products. There are many potential photo scanning resolutions, image enhancement and restoration algorithms, and parameter settings possible for the digital processing. It was not practical to quantitatively test the numerous permutations possible. As such, an experienced analyst selected an appropriate set of algorithms and settings to apply. Additional interactive enhancements were applied "on the fly" by the analysts to assist any specific feature interpretations (e.g., a locally different contrast) that was required to best interpret a specific feature. As with the film-based alternative, the initial analyst's results were reviewed by another senior analyst and any differences in interpretations resolved by review with discussion and consensus for final interpretations.

To avoid possible crossover influence among the analyses, different pairs of analysts were involved for the PI and digital image analyses. The analysts were not provided with any site specific identification or descriptive information. The historical imagery was provided without any site location or descriptions other than film date and scale. Limiting access to collateral information is normally not recommended, as it can hinder interpretations. This extra limitation was applied to avoid possible influences from the ASR results to the new interpretations.

In addition to the primary objectives of range and feature identification and mapping, the locational accuracy of orthophotos developed from the historical photography was tested using USGS and similar quality orthophotos. Recent orthophotos were assumed geometrically correct and used as the basis for control of the historical orthophotos that were developed. Location accuracy was estimated by evaluating offsets between matched pairs of visually distinct feature locations in the orthophotos.

6.2 EQUIPMENT SPECIFICATIONS

The specifications for historical aerial photography are inherently predefined and not subject to change. Available metadata information is often limited to statements of film type (e.g., black and white versus color), scale, and area of coverage. A range of film scanning resolutions was possible for the digital analyses. Photogrammetric applications generally require higher resolutions and geometric fidelity compared to many other image processing applications. Figure 5 provides an example of the four different standard scan resolutions used by USGS-EDC.

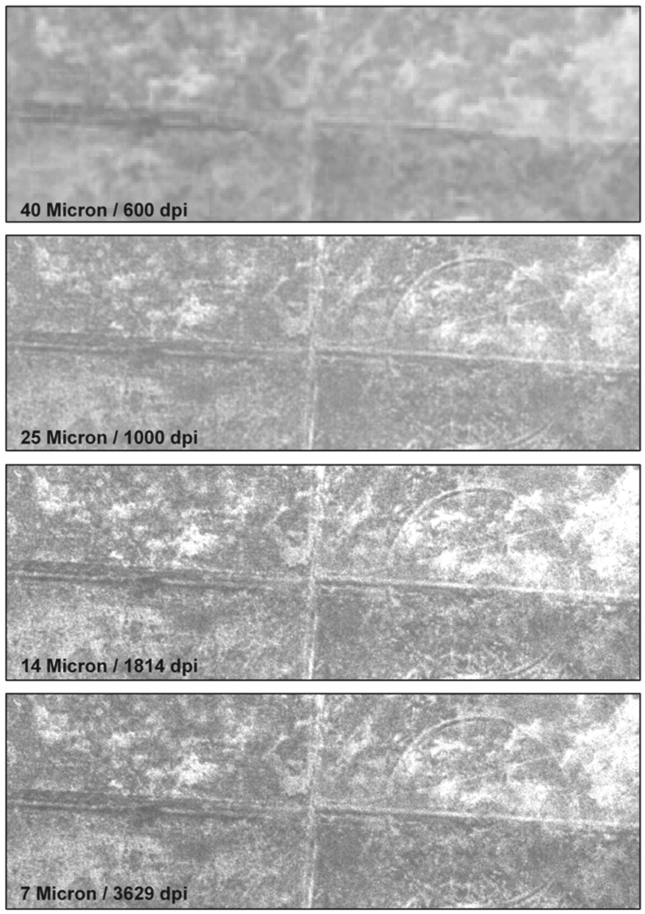

Figure 5. Comparison of film scanning resolutions.

Circular target range on Site #8 – K06TX0267 (Dalhart) 1954 photograph (frame 3994). The bottom three images were from a high quality photogrammetric scanner, while the top image is from a graphics scanner used to generate browse images. All four image scans are from the USGS-EDC. The target circle appears slightly degraded on the 25 micron scan and would not be identified on the 40 micron scan without prior knowledge of its location. The original photograph was acquired in 1954 at a film scale of 1:60,000.
The outer target circle is 1000 ft in diameter.

The USGS-EDC initiated a program in 2009 to systematically scan their aerial photo archive collections to a standard format of 25 microns. They have also discontinued the production of film or print hardcopies for aerial photo products. USGS-EDC photo products are now delivered in digital format only.

6.3 DATA COLLECTION

Historical photography was acquired to match the corresponding set of photography acquired for the ASR studies. Table 3 provides a summary of the photo years and scales acquired for the baseline studies. Detailed citations (mission identifiers, frame numbers, etc.) are available from the corresponding site study reports.

Table 3. Photo data sets used for the comparative analyses.

Site #	Site	Study	Photo Year[1]	Photo Scale
1	Guadalupe Bombing & Gunnery Range K06NM0333	ASR 2001	1950	1:44,000
			1972–74	1:32,000
			1996–98	1:40,000
2	Deming AFB PBR#10 K06NM0394	ASR 1997	1974	1:40,000
3	Kirtland AFB PBR – West Mesa K06NM0445	ASR 1994	1967[2]	1:26,000
4	Kirtland AFB PBR #S-12 K06NM0449	PA 2005 [3]	1951	1:28,400
			1997	1:40,000
5	Walker AFB DBR #35 K06NM0499	ASR 1998	1971–72	1:24,000
6	Kirtland AFB PBR #18 Target S-5 K06NM0619	PA 2004 [4]	1946	1:35,000
			1971	1:40,000
			1996	1:40,000
7	Midland AAF Target Range #14 K06TX0186	ASR 2000	1946	1:20,000
			1966	1:20,000
8	Dalhart PBR Ranges #3 and #4 K06TX0267	SI 2009 [5]	1954	1:60,000

(1) Photo mission campaigns can span months to a few years; the ranges for three multiyear missions are shown.
(2) The 1994 ASR notes several photo-based observations of target features but does not provide a detailed photo date listing. There is one reference to photos taken approximately 1971. The only sitewide photo availability near this timeframe was 1967, which was used as the basis for the comparative analysis. It is possible that the ASR used a combination of other unspecified dates of photography.
(3) No ASR was available at the start of this project; the 2005 PA was used as the source for comparisons.
(4) No ASR was available at the start of this project; the 2004 PA was used as the source for comparisons.
(5) The ASR (1998) for this site did not examine any photography; the 2009 SI map was used for comparisons.

Standard overlapping sets of photos were acquired to allow stereo viewing. Stereo viewing proved less important than anticipated, as nearly all range target features were located on flat terrain. Stereo coverage did prove useful to eliminate the possible misinterpretations of several film artifacts, which are more common in some of the older sets of photography. Figure 6

provides an example of a circular film processing artifact that might be misinterpreted as a bombing range target feature if only the one frame of photography was examined.

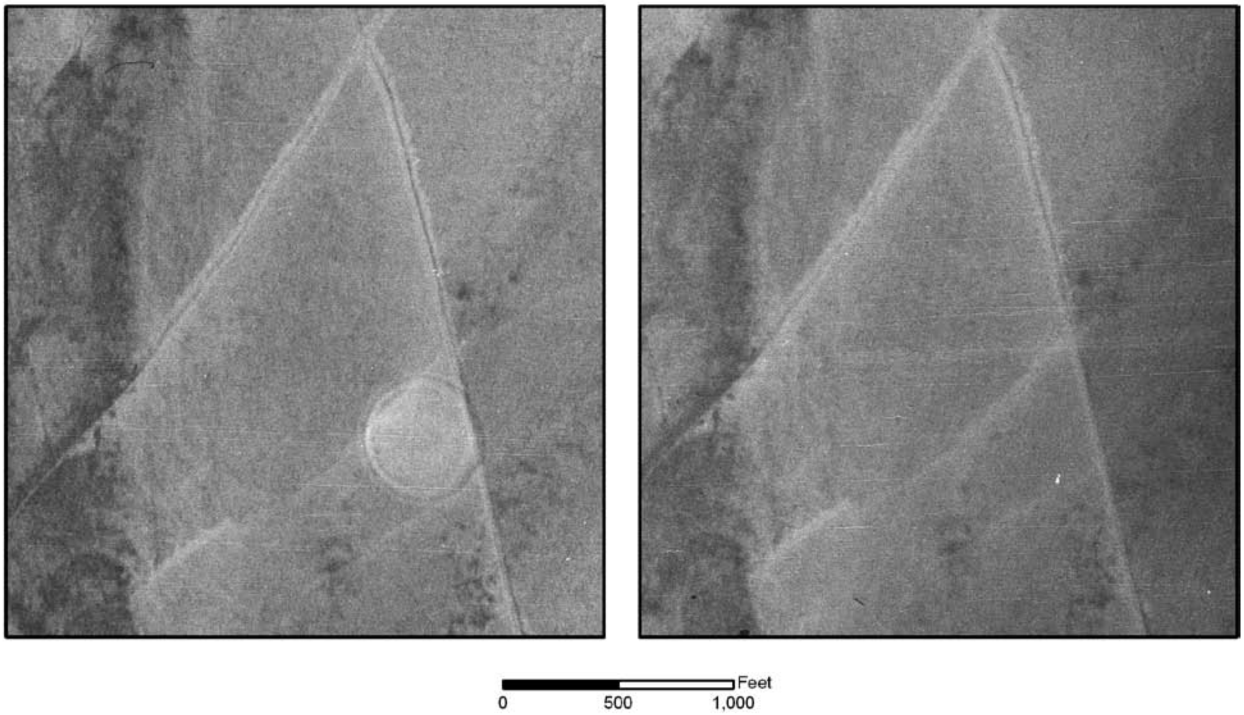

Figure 6. Stereo pair of 1950 photographs with artifact.
The 500-ft circular feature on the photo (enlarged from frame 58) is a film processing artifact. It could be misinterpreted as a target feature based on its circular shape, size, and intersection with a road that could have provided range access. The feature is missing in the overlapping photo (frame 57), which proves that the feature is a film processing artifact. The photos are from Site #1 – K06NM0333 (Guadalupe).

Photos were acquired in both diapositive (film transparency) and scanned digital format. The USGS-EDC has transitioned to a digital-only distribution policy for copies of aircraft and satellite imagery from their archives. This makes the future capability to handle digital imagery mandatory for some photography. Vendors supporting NARA currently support both film duplicate and digital scans of the archive holdings. These and other sources were used to acquire additional photography that was used for validations.

6.4 VALIDATION

Possible interpretation errors can be categorized into two classes – errors of omission (Type I) and errors of commission (Type II). In the context of this project, an error of omission would be to miss the detection of a range feature. An error of commission would be to misidentify a non-range feature by calling it a range feature. Although both interpretations would be considered errors, for this application an omission error would be considered more significant than a commission error – i.e., missing a range would be more significant than calling a non-range feature a range feature. Similarly, missing sites where HE bombs were used would be considered more significant than missing sites used for only practice bombs.

Significant effort was extended to validate all features to the maximum extent that cost considerations allowed. Validation efforts used a variety of sources and methods and a "convergence of evidence" approach to determine if a feature was considered validated. The primary and most productive method was to conduct updated and more extensive searches of historical photo archives and then acquire better dates or scales of photography.

Marginal dates of photography and scale concerns were noted for the following sites:

Date Concerns			Scale Concerns		
Site #2 (Deming)	–	1974	Site #1 (Guadalupe)	–	1:44,000
Site #3 (Kirtland)	–	1967	Site #2 (Deming)	–	1:40,000
Site #5 (Walker)	–	1971/1972	Site #8 (Dalhart)	–	1:60,000

More suitable dates and scales of photography were identified and selected photographs were acquired, in digital format, for all five of these sites. Selected sets of photographs taken prior to range developments were also acquired to assist the interpretation of specific features of interest (see Table 4). Scanning options available from some of the additional sources were highly variable in terms of scanning resolution and quality of equipment. In some instances, validation photos were only available as digital scans of photographic prints using graphic scanners. Although significantly less optimal in terms of image quality, the specific dates and scales available were generally considered to be more important for the validations than the media or type of scanner.

Table 4. Additional photography acquired to assist range and feature validations.

Site #	Site	Photo Year	Photo Scale
1	Guadalupe Bombing & Gunnery Range K06NM0333	1943	1: 50,000
		1946	1: 24,000
		1948	1: 27,230
		1958	1: 17,200
2	Deming AFB PBR#10 K06NM0394	1942*	1: 56,000
		1951	1: 20,000
		1953	1: 54,000
		1956	1: 31,680
3	Kirtland AFB PBR – West Mesa K06NM0445	1935*	1: 44,000
		1945	1: 21,400
		1951	1: 24,000
5	Walker AFB DBR #35 K06NM0499	1946	1: 31,680
		1954	1: 63,000
8	Dalhart PBR Ranges #3 and #4 K06TX0267	1941*	1: 20,000
		1953	1: 20,000

*Photo dates prior to range operational periods.

The additional photography provided sufficient source material to validate nearly all of the photo interpreted features. It also identified several features that had been missed on later dates and/or smaller scales of photography. After review of the additional photography, validation problems did persist for two sites: Site #2 (Deming), which were not fully resolved, and Site #8 (Dalhart), which were validated by field checks.

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7.0 DATA ANALYSIS AND PRODUCTS

The specific processing and analysis steps that were used for the comparison of baseline and alternative methods are discussed in the following sections.

7.1 PHOTO ACQUISITIONS AND PREPROCESSING

Both alternative methods of data analysis began with the acquisition of historical aerial film diapositives (positive transparencies) for the study sites. For direct PI there was no preprocessing of the imagery required. Standard film quality checks were used to document the aerial film characteristics (correct coverage, general brightness and contrast, presence of haze, clouds, or cloud shadows, general sharpness, any film processing streaks, etc.).

For digital processing, the photographs were scanned using photogrammetric quality scanners at high resolution. Initial scanning was performed at the highest available resolution of 7 microns (3629 pixels per inch). The results of the highest resolution scans presented at full pixel resolution were considered too noisy, even after substantial image processing. An empirical comparison of different scanning results led to the selection of 14 microns (1814 pixels per inch) as providing a more practical resolution for scanning the historical photography. The film resolving power of more recent photography may benefit from the higher resolution scanning. A detailed assessment of optimal scanning resolutions for different films and flight acquisition parameters was beyond the scope of this project.

Selective image enhancements and restoration procedures were applied to the imagery to develop the comparative products. These included routine procedures such as brightness/contrast and edge enhancement, as well as the more advanced blur correction, and photogrammetric procedures for orthophoto and DEM generation.

7.2 TRAINING KEYS

Image training keys that provided examples of range features present at other bombing ranges (sites not involved in this study) were used to familiarize the analysts with the types of features to be identified. A classification scheme was developed for the basic types of recognized range features (e.g., target circles, cross-hairs, HE bomb craters, outlines of ships, docks, fuel storage tanks, airfield, train, etc.). An “area of interest” (AOI) feature type was included to identify other features that might have been range related but could not be reasonably defined as range target features.

7.3 TARGET DETECTION AND IDENTIFICATION

The two sets of imagery (film and digital) were interpreted by two sets of experienced image analysts for the visual detection and identification of features comprising a bombing range. Stereo-pairs of imagery were examined for both types of interpretations. The analysts recorded the type and location of each feature and included a basic confidence factor for each feature mapped: confident, probable, or possible. Additional AOIs, such as towers and building structures, were also annotated but not incorporated into the comparative analyses. Film analysis results were initially annotated onto photo overlays and then transferred into GIS format using

orthophoto bases. Digital interpretations were directly mapped onto orthophotos using GIS techniques to record the location and attributes of range features.

7.4 DATA PRODUCTS

Comparative data sets of photography for the PI and digital scans for the DIP analyses were prepared for each site. Additional photography and other collateral data were collected to assist the validation effort. Figure 7 provides a time series example of four dates of photos for the N-1 Range area of Site #3 (Kirtland – West Mesa). It was noted that in 6 years (from 1945 to 1951) the range features became much less distinct and a bridge or convoy target observed on the 1945 photo was no longer apparent by 1951. The much later 1967 photography was used for the comparative analysis. By that time frame, only the primary target circle and cross-hairs remained evident, and several other target features were missed by the interpreters. The time series example reinforces the critical nature of acquiring an appropriate set of historical photography to map range features.

Figure 8 provides an example of a false alarm (commission error) from Site #3. A hexagon layout of building features is evident, with several access roads still visible on the 1967 photography that was used for the comparative analyses. Earlier dates of photography documented that this complex was developed sometime between 1951 and 1967, which is after the range operational period. Both the PI and DIP analysts interpreted this feature as a possible target.

Site-wide aerial photo coverage acquired in 1951 was obtained for Site #3 and used as the basis for developing digital orthophotos. A mosaic of these orthophotos is presented as Figure 9. The historical orthophotos were used as the mapping base for new interpretations. Partial coverage of the site was also obtained for 1945, which was noted earlier. These additional photos were georeferenced to the orthophoto mosaic.

Some of the validation photography was acquired from sources that only had duplicate prints and no photogrammetric quality scanners available. Although less than optimal, in many instances this photography covered critical time periods and provided useful information for the validations. Photos were also acquired for three sites for dates prior to range operations: 1942 photos of Site #2 (Deming), 1935 photos of Site #3 (Kirtland–West Mesa), and 1941 photos for Site #8 (Dalhart). These photos were acquired to help validate specific site features that were considered possible pre-existing features that were not range activity related. NARA estimates that 85% of the continental United States has such pre-WWII photography available (NARA, 1973).

Validation data sets included ASR maps and other site descriptions available from various historical documents. The site related maps that were considered pertinent to PIs were usually georeferenced. This facilitated the interpretation process by allowing the use of GIS techniques. Any subsequent analyses, such as SI results, were also examined and were used whenever appropriate. These more recent studies usually included GIS datasets that could be readily incorporated into the site datasets used for validations.

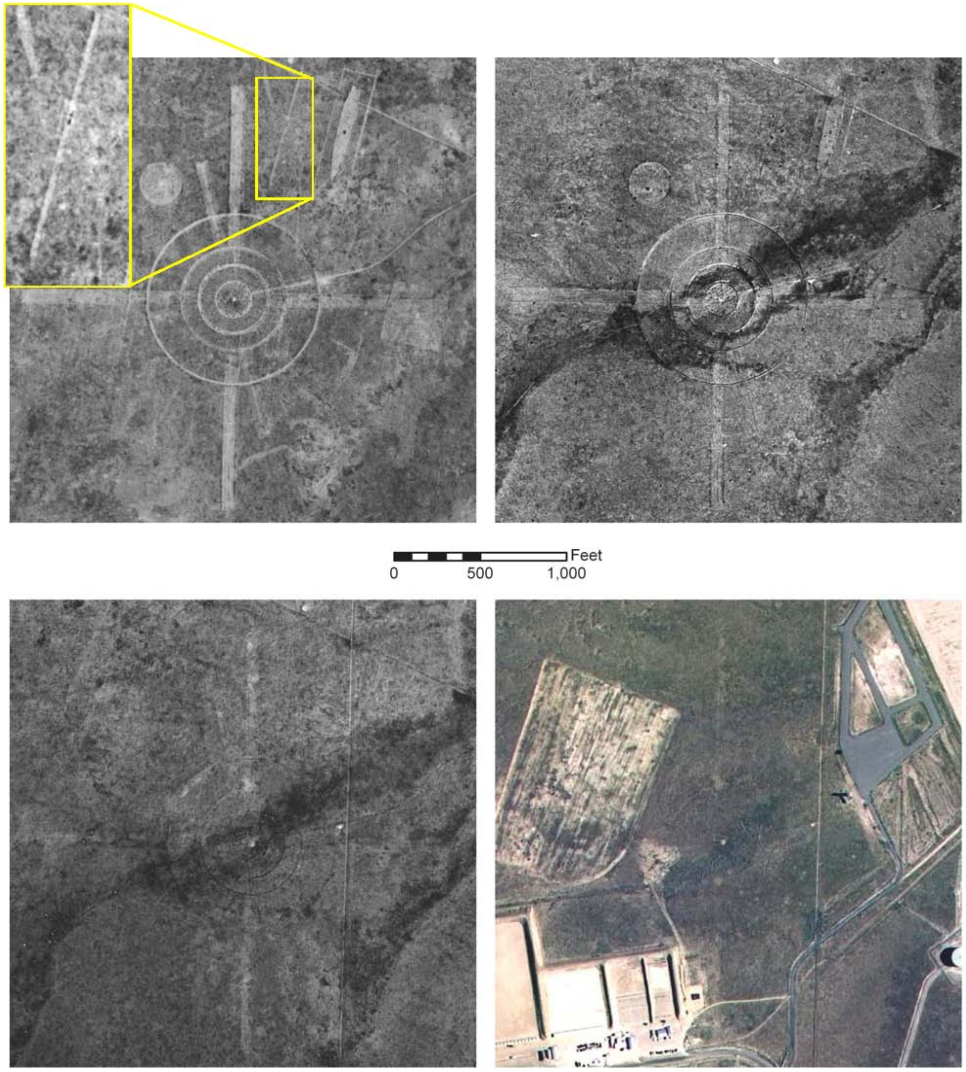

Figure 7. Time series of Site #3 - K06NM0445 (N-1 Range Area).

This range has a bridge or convoy target evident in the 1945 photograph (yellow box) that is no longer apparent by the 1951 time frame. The comparative image analyses in this study were based on the 1967 photography. In the 1967 photograph the target circles and cross-hairs are still evident, but several other targets are no longer apparent. By 2005, the target features are barely discernable or have been obscured by development. Historical documents noted that the original cross-hairs were developed using magnetic north instead of true north and had to be redone for correct usage by navigators, thus explaining the offset shorter cross-hairs that are most evident in the 1945 photo. Original photo scales ranged from 1:21,500 to 1:26,000. The nominal presentation scale shown here is 1:10,000.

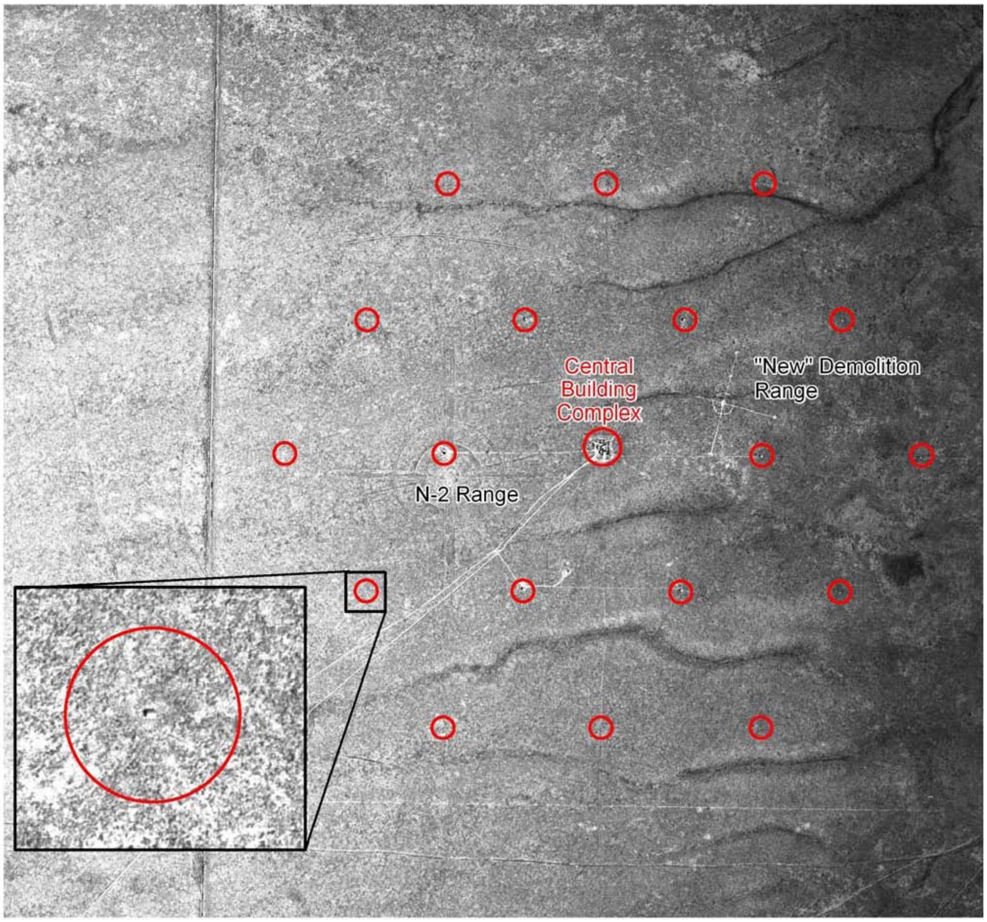

Figure 8. Hexagon building layout on site #3 - K06NM0445 (Kirtland - West Mesa).
Small buildings or sheds around a central building complex were noted on the 1967 photos. The complex was located between the inactive N-2 and New Demolition Ranges. These features were identified as possible range features by the IP and DIP analysts. Range activities were reported to have ended in 1945 and these feature are not evident in the 1951 photographs. Due to the time frame of their development, the validation effort concluded that these were not related to the WWII bombing range activities. The original photo scale was 1:26,000. The presentation scale of the photo shown above is about 1:16,000.

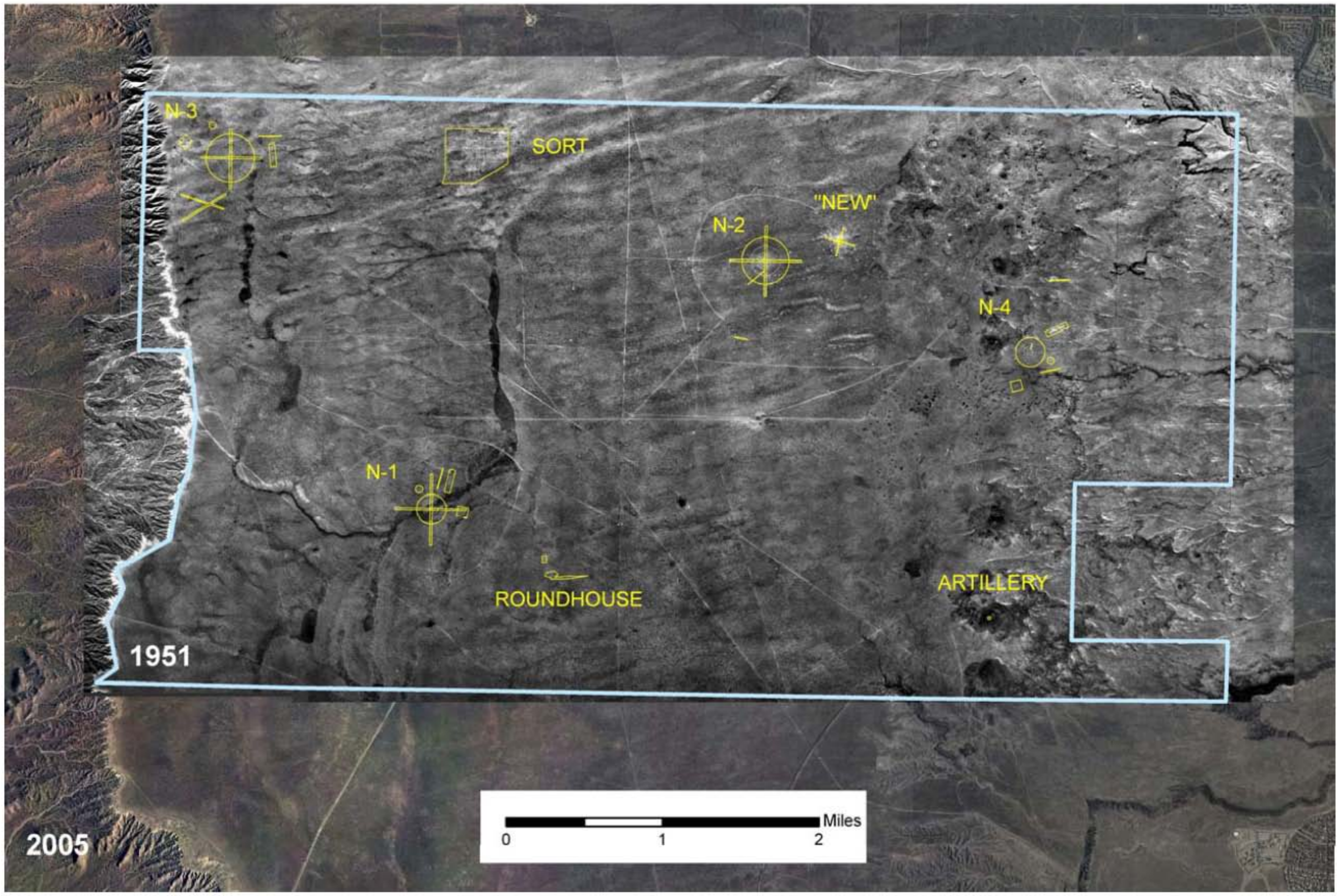

Figure 9. 1951 digital orthophoto mosaic of Site #3 - K06NM0445 (Kirtland - West Mesa).

The background image is the 2005 color orthophoto used for control. Munitions ranges are outlined and labeled in yellow. The 1951 black and white orthophoto mosaic was developed from 11 photos. The overall FUDS outline is shown in light blue. The SORT range was a Simulated Oil Refinery Target. Distinct HE craters are apparent around the New Demolition target. The field heavy artillery target was the only target not located on flat terrain. Careful examination of trail networks was useful at many sites to identify likely target areas. Historical documentation noted the need for roads and trails to service the targets.

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8.0 PERFORMANCE ASSESSMENT

A summary table of the validated interpretation results for the performance objectives is presented below (Table 5). More extensive descriptions and a tabular listing of site-specific feature interpretation results are provided in the project final report (TerraSpectra, 2010). The success criteria for three of the nine performance objectives were not fully met: #3, #5, and #9.

Table 5. Performance assessment results.

Performance Objective	Metric	Success Criteria	Results
Quantitative Performance Objectives			
1. Visual identification of all bombing range areas	Percent detected	100% detection	ASR: 72% (21/29) √ PI: 97% (28/29) √ DIP: 100% (29/29) √
2. Limited false alarms for bombing range areas	Percent of areas incorrectly identified as ranges	< 50% false alarms	ASR: 0% (0/29) √ PI: 3% (1/29) √ DIP: 3% (1/29) √
3. Identify all range target features (outlines of ships, docks, airstrips, etc.)	Percent detected	> 90% detection	ASR: 42% (33/79) PI: 75% (59/79) DIP: 84% (66/79)
4. Limited false alarm rate for range target features (above)	Percent of features incorrectly identified as range target features	< 50% false alarms	ASR: 0% (0/79) √ PI: 4% (3/79) √ DIP: 4% (3/79) √
5. Identification of ranges with craters (inferred use of HE munitions)	Percent detected	> 75% detection	ASR: 70% (7/10) PI: 60% (6/10) DIP: 70% (7/10)
6. Feature mapping location accuracy	Average range and target feature mapping location error	< 10 meters offset	ASR: 28.6 m PI: 2.4 m √ DIP: 2.2 m √
7. Interpretation production rate	Time required to analyze each stereo-pair of photos	< 1 hour/photo pair	PI: 49 min/pair √ DIP: 57 min/pair √
8. Orthophotos from historical photos	Average point location offset errors	< 10 m	2.3 m √
9. DEMs from historical photos	Percent correct detection of craters	Improved crater detection	No improvement noted
Qualitative Performance Objective			
10. Ease of use and technology transfer	Digital image restoration and enhancement techniques relatively straightforward to implement with positive improvements in interpretation results; photogrammetry and stereo viewing hardware and software are comparatively more expensive and tedious to implement. √		

√ = Indicates project success criteria met.

Performance Objective #9, high resolution DEMs for improved crater detection, was anticipated to be exploratory in nature. Upon detailed analysis, the photographs examined did not allow suitable elevation posting density to identify craters.

The success criteria for Performance Objective #3, the identification of all range target features, was set high (90%) and nearly met by the DIP method (84%). Performance results for the PI and

DIP methods were both higher than the ASR results, mapping up to twice as many range-related features. The DIP method proved 9% better than the PI method, correctly identifying seven more features. Three of these were faint air-to-air gunnery range (ATAGR) markers at Site #1, where image contrast enhancements and sharpening proved useful. The remaining five features included two bridge or convoy targets at Site #3, a ship target at Site #4, and an HE target circle at Site #8. The use of older dates and better resolutions of photography, however, allowed the validation of an additional 13 range features. The availability of these older dates of photography was considered the most significant factor for the validations.

A majority of the interpretation omissions occurred at Site #3 (Kirtland – West Mesa), where the 1967 time frame of the photography was not suitable for identifying many of the features. Similar problems were encountered at Site #2 and Site #5, where the earliest dates of photography used for the ASR investigations were 1974 and 1971, respectively. Less common as a limiting factor was photography scale; the DIP results for 1954 photography of Site #8 (scale 1:60,000) missed two features that were distinct on better resolution (scale 1:20,000) photography acquired just one year earlier (1953).

The success criteria for Objective 5, the identification of ranges with craters, was set at 75%. Overall, the results for identification of craters were comparatively similar among the methods. Both the ASR and DIP approaches found 7 of 10 areas with craters, which at 70% is below the success criteria of 75%. The DIP and PI approach did not identify three crater sites on Guadalupe, but the PI approach identified one additional crater area on another site (Site #5) and the DIP approach identified additional crater areas on two other sites (Sites #5 and #8).

Based on prior review of ASR documentation, it was anticipated that the HE ranges would be more readily distinguished by the presence of numerous craters. This proved true for the four heavily used demolition ranges examined in this project. However, several instances of very limited HE use occurred on ranges found on Site #1 (Guadalupe). Documentation indicates that some practice ranges had limited HE usage for secure (classified) testing that may have involved only a small number of HE bombs.

Site #7 (Midland) presented another limited HE range situation. According to ASR (2000) documentation, the Army Air Corps invited local residents to a July 4th, 1944, demonstration air show that involved the use of HE bombs over a formation of vehicles, the remnants of which were noted during field investigations. The relatively uniform landscape conditions of this site and availability of timely (1946) and excellent scale (1:20,000) aerial photography allowed ready identification of the HE craters. The more variable landscape conditions and later (1950) photography at a smaller scale (1:44,000) that was used for Site #1 (Guadalupe) made similar identifications more problematic.

9.0 COST ASSESSMENT

Cost information for the demonstration project was tracked for several key activities. A substantial amount of prior experience on similar historical PI projects was also available and reviewed. Based on this information a basic cost model was developed for operational costs of the recommended DIP approach. Capital costs were also collected for the necessary hardware and software needed. Potential training costs, however, are not addressed.

9.1 COST MODEL

Table 6 summarizes estimated operating costs of PIs for two site sizes:

- 1 square mile sites, such as Site #6 (Kirtland AFB PBR #18 Target S-5)
- 20 square mile sites, similar to Sites #3 (Kirtland – West Mesa) and #8 (Dalhart)

Table 6. Operating cost model for digital image processing and interpretations.

Cost Element	Data Tracked During Demonstration	Estimated Costs Small Site 1 Square Mile (640 acres) (250 hectares)	Estimated Costs Medium Site 20 Square Miles (12,800 acres) (5,180 hectares)
Archive search and data management	– Hours required – Personnel required – NARA search subcontract	$1150	$1150
Photo scanning	– Cost per frame – Number of frames	$900	$1800
Pre-processing of imagery	– Hours required – Personnel required	$1300	$2340
Image interpretation and review	– Hours per stereo pair – Number of stereo pairs – Personnel required	$1040	$1820
Data compilation and QC	– Time required – Personnel required	$260	$520
Project management	– Time required – Personnel required	$640	$640
TOTAL COST PER SITE Cost per hectare (Cost per acre)		$5290 $21.16 per hectare ($8.27 per acre)	$8270 $1.60 per hectare ($0.65 per acre)

It was assumed that a minimum of three dates of stereo photography would be acquired for each site. Additional dates of photography would increase costs proportionately. The need for additional dates should be based on site-specific conditions. It was also assumed that one historical orthophoto would be prepared and used as a base for mapping interpretation results. Simpler georeferencing techniques were assumed for the other dates.

The historical photo scales examined for this project ranged from 1:20,000 to 1:63,000. At the preferred 1:20,000 scale, each frame covers about 8 square miles (2,072 ha). Each frame at 1:63,000 scale covers about 80 square miles (20,719 ha). Smaller scale photography (e.g.,

1:63,000) can sometimes prove inadequate for small features, but may still be useful if it is the only photography available for a critical time frame.

Figure 10 provides an example of 1:20,000 versus 1:60,000 scale photos for Site #8 (Dalhart). The 2009 SI made use of the 1:60,000 scale photos (1954) and did not identify the HE range location. The PI and DIP interpretations both identified a probable HE range in this area from the 1954 photos. The 1:20,000 scale photos (1953) were used to validate the HE range and also allowed two additional range features to be identified.

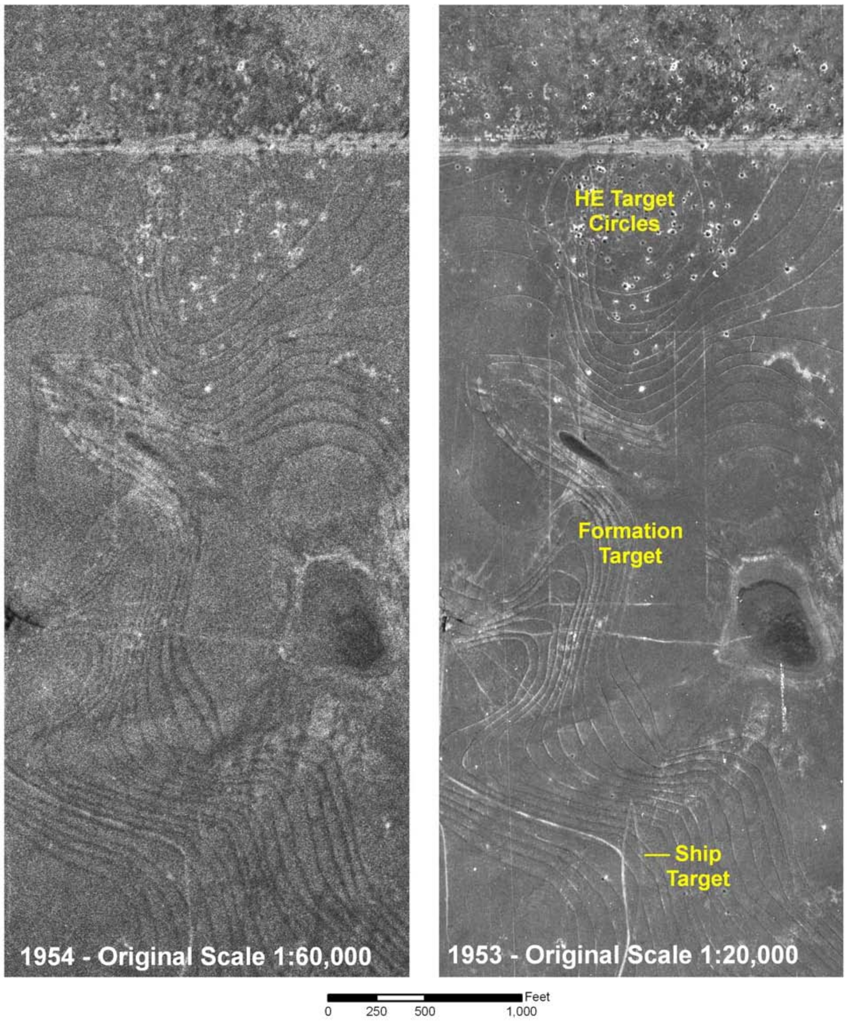

Figure 10. Original photo scale comparison.

Difference between the original photo scales results in substantially better target detection on the larger scale (1:20,000) photos. Contour farming practice at this site made interpretations difficult. The ship target feature was not initially validated on the 1953 photos until a target layout map included in the ASR documentation was reviewed. The layout map included target shapes, sizes, and distances between the three targets, but incorrectly located the series of targets as being in the middle of the site, about one third of a mile west of their actual location. The 2009 SI used the 1954 photography but did not identify the HE range and craters or the other targets noted above. The PI and DIP analysts correctly identified the HE range and craters on the 1954 photographs but missed the other two targets.

In addition to scale, the specific number of frames required for stereo coverage of a site also varies by the alignment of the photo mission flight lines and camera stations. Film acquisition, scanning, preprocessing, and some other costs do not become proportionally linear until site sizes are larger than the area covered by individual frames of photography. As shown in Table 6, the costs per unit area are estimated to be substantially lower for the 20-square mile site versus the 1-square mile site. Sites larger than 20 square miles would scale in a more linear fashion, especially for larger scale photos.

The operating cost model does not include costs to develop a report documenting interpretation results. Nor are costs to develop appropriate training keys and train personnel in procedures included. Training costs can vary significantly depending upon the prior qualifications of the personnel involved.

Capital cost estimates for appropriate hardware and software are summarized as follows:

High capacity computer workstation		$5000
Stereo viewing display monitor		$4500
Image processing software with 3-D photogrammetry modules		$8500
Basic GIS software package		$1500
	Total	$19,500

A high capacity workstation is recommended due to the substantial image file sizes and processing requirements for advanced image processing algorithms. Such workstations have multipurpose uses and are relatively common for technical analysts. Appropriate image processing and GIS software are also relatively standard and have multipurpose uses. The stereo viewing display monitors that are integrated with specific image processing and photogrammetry software, however, are relatively specialized.

9.2 COST DRIVERS

As indicated by Table 6, the primary cost drivers for historical PIs are related to photo searches, scanning and preprocessing of digital imagery, and the image analyses. The results of this demonstration project indicate that the historical documentation and aerial photography used for existing range definitions should always be reviewed to ensure their suitability.

9.3 COST BENEFIT

Earlier PIs of 2005 digital orthophotos to support the New Mexico statewide FUDS GIS database development identified several mislocated ranges and additional range target features. These PIs helped focus SI efforts and avoided potentially costly rework for several MMRP sites. The results of the PIs greatly reduced the required area to be traversed and sampled during the SI field efforts, resulting in a much more satisfied regulatory community as pertains to the attainment of the Data Quality Objectives in the MMRP SI program. As demonstrated in this project, a more systematic review and use of historical photography can potentially provide even more benefits.

A detailed cost benefit assessment was not possible for this demonstration. Several missing or mislocated range target features were observed within the selected study areas demonstration project. These features included an HE range that was not identified in a recent 2009 SI (Site #8, Dalhart). In addition, five distinct bombing ranges that do not appear in the current FUDS MMRP inventory, and not related to the selected study sites, were identified during the course of photo reviews for this project. The locations for these sites have been forwarded to the USACE for a review of their potential FUDS status.

10.0 IMPLEMENTATION ISSUES

The use of film diapositives instead of prints for historical PIs is a relatively straightforward step with only modest cost impacts for specialized equipment. Much of the benefits can most likely be obtained using intermediate level equipment (light boxes and mirror stereoscopes with magnifying optics in lieu of more expensive stereo zoom equipment). However, photographic film archives are steadily moving towards a digital future that already requires the use of DIP for photos from some primary archive sources.

Digital image products have also become a standard element of GIS databases. This project demonstrated that DIP results generally surpassed optical PI results. Implementation of DIP for improved analysis of historical aerial photographs is therefore recommended as the preferred method of analysis for this application. Based on this and similar projects, some basic general guidelines for improved use of historical photography are summarized below:

- Collect available archive data and define expectations for the site:
  - Previous reports often provide substantial insights about a site's history and what type of features are to be expected.
  - Analysts need to be flexible and open to finding unexpected features, but blind PI unnecessarily hinders efficient analyses.
- Review available analysis results, such as:
  - Visibility of distinct features on available photos.
  - Time frame of available photos, ideally from the operating period or shortly thereafter. If needed, earlier photography can sometimes help identify pre-existing features.
  - Suitable resolution (primarily scale) to see detail; a scale range of 1:15,000 to 1:25,000 is preferred, when available, although scales up to 1:60,000 have been found useful when better scales are not available.
  - Stability of landscape—sandy and windy environments are likely to more rapidly obscure range features, as can agriculture or urban development.
- Conduct extended photo search (if needed):
  - Review national and regional photo sources.
  - Recommend pre-activity period and post-activity photos; decade intervals may be adequate for post-activity review (to avoid unrelated false alarms).
- Acquire diapositive copies or digital scans (preferred) from original source materials.
- Preprocess imagery for basic brightness and contrast, blur, noise, and edge enhancements.

- Georeference all photos (minimally) and create orthophotos if terrain conditions are a significant factor (i.e., hilly or mountainous).
- Develop a set of training keys with descriptions.
- Develop a suitable classification scheme:
  - Include confidence criteria (e.g., confident, probable, possible).
  - Include open AOI for additional items, with comments.
  - Map transportation features (roads and trails).
- Monoscopic viewing may be adequate for some features, but stereo viewing is recommended and sometimes required.
- Use a GIS data collection framework to record and attribute interpretation features.

This approach allows other datasets to be viewed in context and supports the "convergence of evidence" required for some interpretations.

An extensive and growing set of historical aerial photo archives exist. These archives are becoming more readily searchable with improved finding aids. The need to conduct updated historical photo searches can be critical to the identification of appropriate dates and scales of photography for FUDS MMRP assessments.

The trend to digital scanning of these archives is clear, and DIP has become a requirement for using some sources of imagery. Similarly, the use of historical photos in a GIS framework, which can facilitate interpretations, requires digital imagery. As demonstrated by this project, the interpretation of digitally processed imagery provided results that were systematically similar or better than analog film interpretations.

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APPENDIX A

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